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DTU Aqua
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Preface

This DTU Aqua report is identical to the final monitoring report which was part of the overall project report, "Rebuilding of Marine Cavernous Boulder Reefs in the Kattegat (Blue Reef)" (LIFE06 NAT / UK / 000159) to the EU LIFE on 1 July 2013.

In consultation with DCE, Aarhus University and Danish Nature Agency it was decided to publish the report in DTU Aqua report series to make it easier to refer the (ISBN number etc.) and increase its visibility.

AARHUS UNIVERSITY
DCE - DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Technical University of Denmark

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1 Introduction

1.1 Background

Offshore boulder reefs have a high biodiversity and are a rare and biologically important reef type at the national and European level. Reef habitats are one of the few marine habitat types that are included in the EU Habitats Directive and for this reason 51 reef areas are included in the Danish Nature-2000 network. In Denmark, boulder reefs in shallow waters have been extensively exploited habitats targeted for their high concentration of easy-to-collect large boulders for constructing sea defences and harbour jetties. This has destroyed an important habitat with a high biodiversity including cave dwelling species.

The reef at Læsø Trindel within the Nature-2000 site Læsø Trindel and Tønneberg Banke in the Northern part of Kattegat (*Figure 1*) is one of the shallow water reefs severely affected by extraction of boulders.

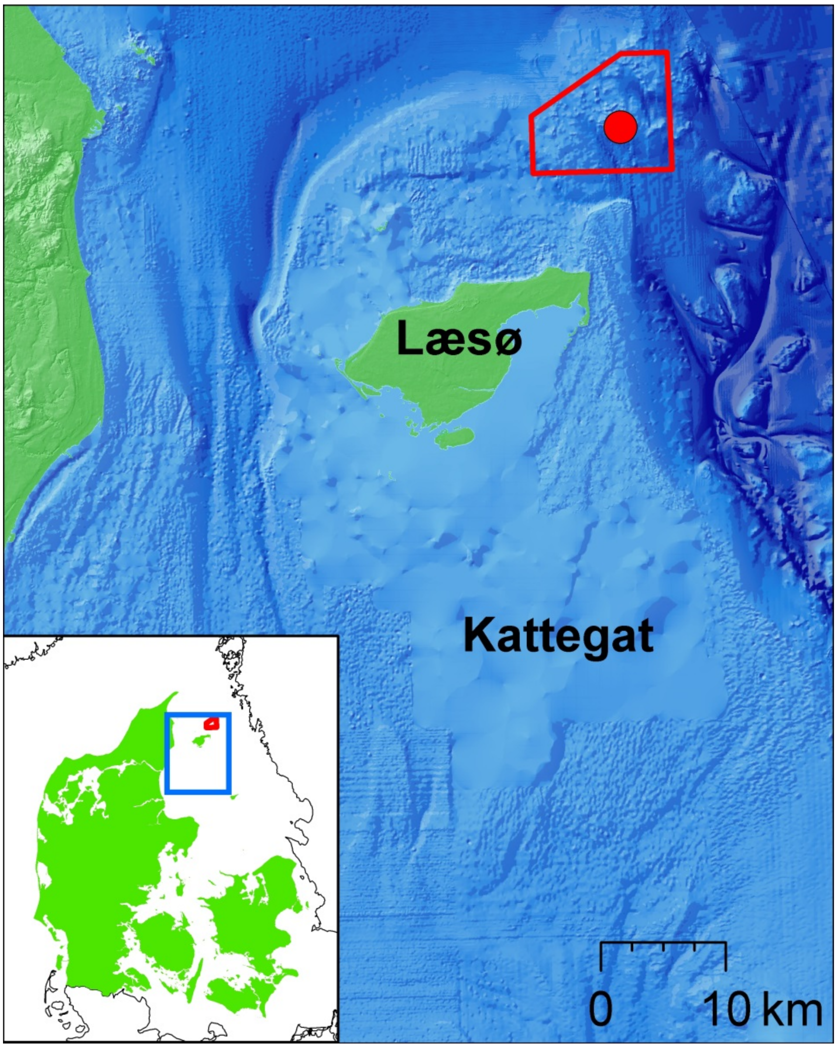


Figure 1. Location Læsø Trindel within the NATURA 2000 site No. 168 “Læsø Trindel and Tønneberg Banke” in Kattegat (marked by red border).

The oldest available maps show that the water depth at Læsø Trindel was four ft equal to 1.25 m in the period from 1831 to 1911. In 1930 the first evidence exists of boulders removed from the reef top and later maps show a continuously increasing water depth on Læsø Trindel (*Figure 2*) until approximately four m depth was reached in the 1970s.

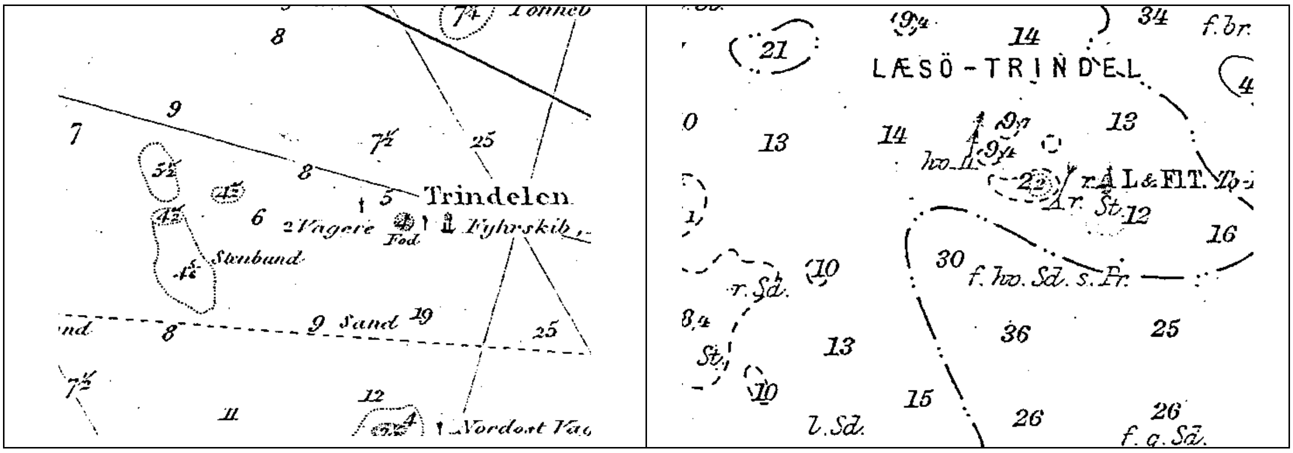


Figure 2. Old maps showing the water depth at Læsø Trindel. The left map is from 1831 showing that the top of the reef was just 4 feet (1.25 m) below the surface. The map to the right is from 1930 and at that time the top of the reef was 2.2 m below the surface.

Læsø Trindel was included as a monitoring site for macroalgal vegetation in the National Marine Monitoring Program in 1991. The results of the monitoring clearly demonstrated that the status of the reef was not satisfactory. The shallowest part of the reef was left with a vast majority of stones in the size class from 10-20 cm, and the biological components with dominance of opportunistic species indicated a fast turnover rate which is not common at other reefs with the same depth distribution and exposure. A continuous break down of the reef was indicated by yearly findings of larger algal species still anchored to stones that have tumbled down the reef slope to rest at 18 m water depth at the foot of the reef (*Figure 3*). The reef was obviously not in a stable condition due to the high physical stress caused by waves on this open water location compared to the relative small size of stones left on the reef.

Figure 3. Laminaria plants anchored to small stones and transported to deep water at the base of Læsø Trindel. Photo: Karsten Dahl

1.2 The restoration of the reef at Læsø Trindel

The actual restoration of Læsø Trindel took place from June to September in 2008. Approximately 100,000 tons of large boulders were shipped on a barge from a Norwegian quarry and deposited at three predefined areas at Læsø Trindel during eight trips (*Figure 4*).

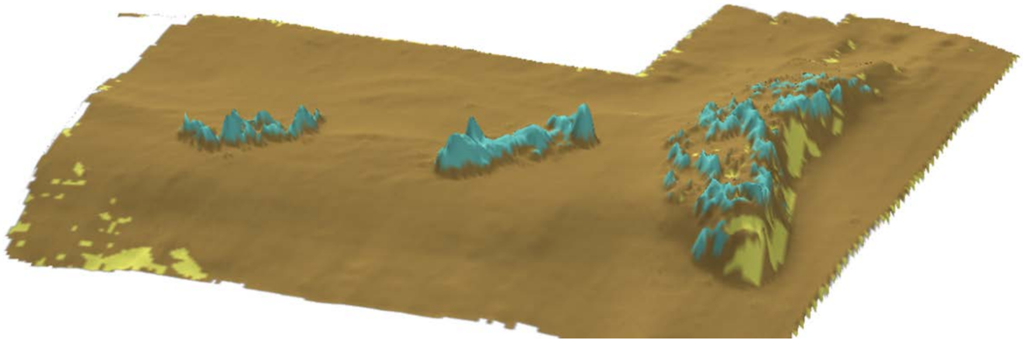


Figure 4. Seabed map showing the three restored reef structures at Læsø Trindel. The turquoise colours indicate an increase in the average seabed level with > 0.5 m/25 m^2. The overall project area is approximately 4.5 ha.

The western and middle sites were located at approximately 9-10 m water depth and in those areas the main focus was to create piles of cave forming reef structures 5-6 m high. At the eastern site the shallow area from 4-6 m was stabilized with a more or less dense cover of boulders covering a large area. In addition a 2.5 m pile of large boulders restored the former water depth of 1.5 m below the surface.

Approximately 27,400 m^2 of seabed was covered by new boulders. The depth interval 1.5 to 4.5 m comprised 7,175 m^2, 4.5 to 7.5 m depth comprised 11,725 m^2 and the deepest part from 7.5 to 10 m water depth covered an area of 8,500 m^2 (*Figure 5*).

Inspections carried out after the last barge trip revealed that minor adjustments of the new reef structures was necessary to fulfil the planned design of the new reef. Reposition of some boulders took place in June 2009.

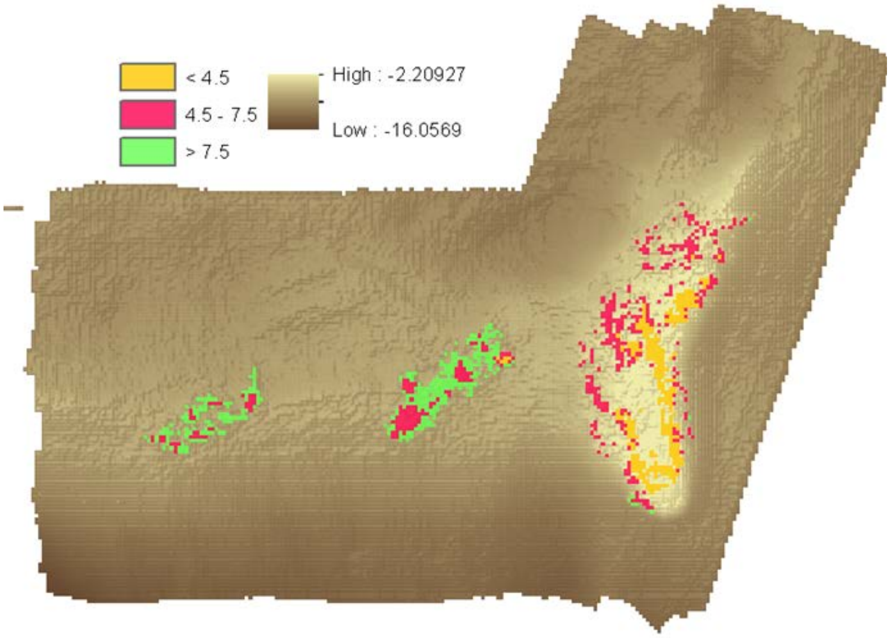


Figure 5. Area covered by the new boulders at three different depth intervals.
Yellow colour: 1.5-4.5 m water depth.
Red colour: 4.5-7.5 m water depth.
Green colour: 7.5-10 m water depth.

1.3 Aim of this work

The “Blue Reef” monitoring programme uses a “BEFORE - AFTER” approach with monitoring activities before and after the restoration of the boulder reef. A baseline study was carried out at Læsø Trindel in 2007 (Dahl et al. 2009) focusing on a number of key variables describing the overall quality of a reef habitat before the restoration projects began. In 2012 the area was revisited using the same methodology and sampling programme.

In between 2008 and 2011, an extensive surveillance was carried out at specific stations on the new boulders to follow the colonisation of new species. The surveillance was done by a taxonomically skilled diver reporting the cover of larger algal and fauna species on the new boulders. The results of the surveillance were used to prolong the overall project period with an extra year to compensate for the delay in the reef construction phase.

To document the benefit of the restoration project on ecology and biodiversity of Læsø Trindel the following sampling methods were applied in 2007 and 2012:

- On site diver surveillance to document physical stability and structure of the reef. This is a key indicator for assessing physical stability and structure of the reef.
- Suction sampling to collect fauna and flora specimens in order to estimate biomass, abundance and species diversity of bottom fauna and flora per m^2 on stable hard substrate and unstable substrate. This is a key indicator for documenting the development of the biological community and provides a quantitative and qualitative estimate of biological diversity and biomasses of species. It will also provide data for comparison with the fish stomach analysis and document the expected gain in physical and biological structure and function of the restored boulder reef.

- Fishing with scientific multi-meshed gillnet, supplemented with fyke nets, to collect fish fauna. The gillnet consists of different mesh sizes ensuring unbiased fish catches in a large size range. This provides information on the length distribution of fish species, fish biodiversity and their relative abundance and distribution.
- Fishing with lobster traps to sample European lobster (*Homarus gammarus*) and brown crab (*Cancer pagurus*) to estimate abundance and distribution of these species. The population of European lobster was monitored as a key biodiversity indicator for species of cavernous reefs.
- In order to quantify the change in food-web dynamics i.e. closer link between prey availability and food ingested by resident species, stomach content analyses were conducted on cod (*Gadus morhua*) and goldsinny wrasse (*Ctenolabrus rupestris*).

2 Material and methods

2.1 Physical environment

Data on the average salinity is available from nearby hydrographic sampling stations stored in the national marine monitoring database MADS at Aarhus University (AU) (former National Environmental Research Institute, NERI).

Data on bathymetry is available from several sources. The Geological Survey of Denmark and Greenland (GEUS) surveyed the area in 2005 using a multibeam echo-sounder before the restoration took place. In 2009 and 2012 mapping was done on behalf of the National Environmental Agency to document the new bathymetry as well as the stability of the new reef structures.

2.2 Sampling macrophytes and benthic fauna

Sampling on the seabed for biomasses of macroalgae and benthic fauna and for abundance of benthic fauna was conducted from 29 June to 4 July 2007. This was a little more than one year before the new boulders were placed at the seabed. A new investigation was then carried out from 29 May to 1 June 2012 close to the end of the funding period for the overall project.

Sampling in both years was carried out using a suction sampler and a 1 mm filter system operated by divers (*Figure 6*). This sampling system had previously proved efficient for collecting both sessile and mobile hard bottom fauna as well as seaweeds.

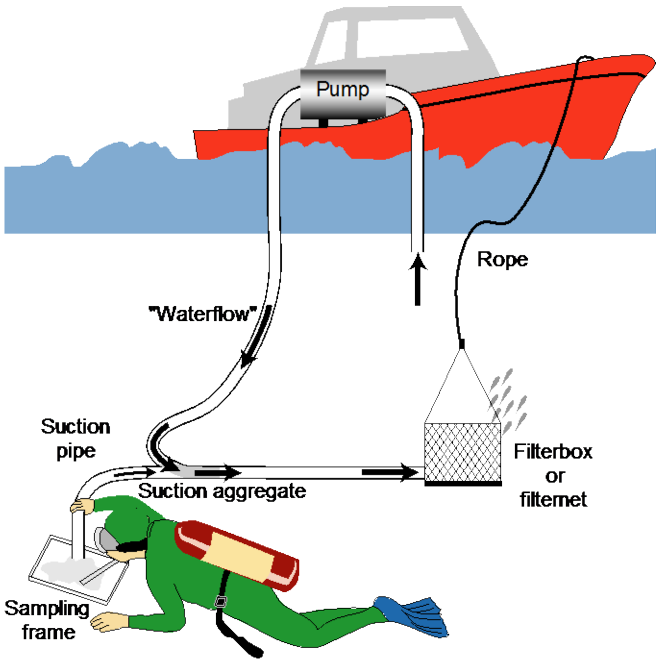


Figure 6. Suction sampling. The filter is either a box with 1 mm stainless mesh size used for sampling sand, gravel and small stones or a net made of plastic with the same mesh size used for sampling macroalgae and fauna scraped off from larger stones and boulders. Drawing by Britta Munter.

2.2.1 2007 sampling

All samples were taken within areas where the restoration with boulders were planned to take place. Eight samples were taken at the western part of the reef, at 9.6-9.9 m depth, at three anchor sites. Six samples were taken at the middle part, at 9.4-9.6 m depth, at two anchor sites and 14 samples was taken near the eastern top of the reef, at 5-6.2 m depth, at four anchor sites. Information on the different samples is given in Appendix 1 and the geographic distribution is shown in *Figure 7*.

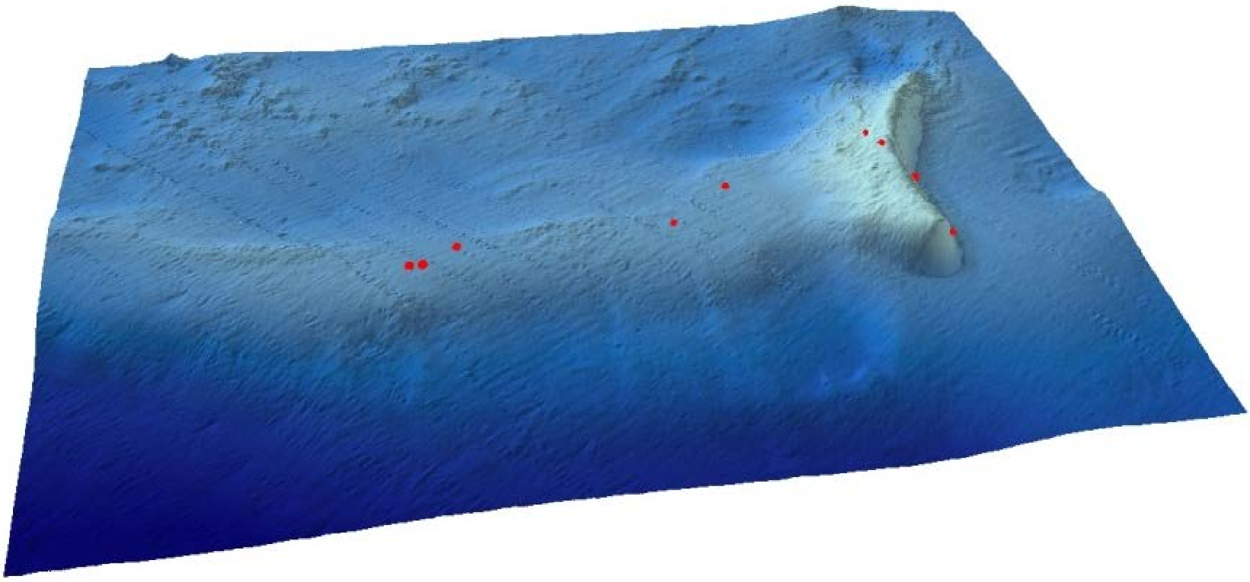


Figure 7. Bathymetry of the Læsø Trindel and the surrounding seabed including suction sampling anchor sites at Læsø Trindel. The map is based on multibeam data collected by GEUS.

The sampling was planned to focus on the surface of the expected gravel/ boulder dominated seabed, but at some sampling stations gravel was almost or totally missing and the seabed was dominated by rough sandy sediment. Suction sampling included the upper 10 cm of the seabed. In cases where stones were too big for the suction sampler they were picked by hand and added to the filter box. In a few cases where larger boulders too big for handpicking were located inside the frame, biota were detached with a putting knife during suction.

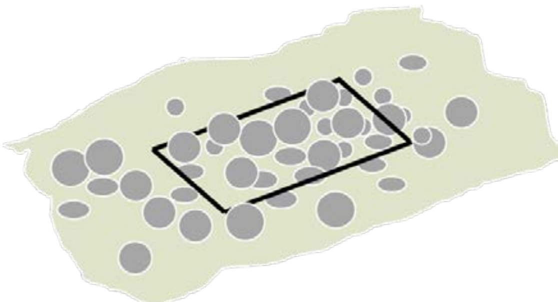


Figure 8. Frame sample on sandy-gravely seabed. Frame size 1/6 m and sampling depth 10 cm down in the sediment.

Sampling took place within 1/6 m^2 metal frames dropped arbitrarily on the seabed on instructions by the dive operator while the diver was swimming over the seabed. Stones too big for the suction pipe (diameter ≥ 10 cm) were collected by hand and stored in the filter box, when suction was completed.

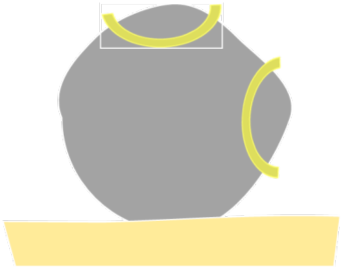
2.2.2 2012 sampling

Sampling took place on two anchor places on the new western boulder structure, two on the new middle structure and five on the new eastern structure (*Figure 10*).

Samples from the new boulders were taken within a slightly flexible 0.1 m^2 circular frame. Biota were detached from the boulder surfaces with a putty knife during constant suction.

Frame samples were taken at the top of the boulders as well as on the side of the boulder (figure 9). A total of 12 "top" and "12" side samples were taken on the western and middle structures and 19 "top" and 19 "side" were collected from new boulders on the eastern structure. Eight samples were taken at app. 3 m water depth, 24 samples from 6-7 m depth and 30 samples from 9-10 m depth. The samples were equally split between "top and side" in each depth interval.

Figure 9. Frame sampling on the top and on the side of big boulders. Frame size is 0.1 m^2. On an idealized round boulder with 1 m in diameter this is 0.1034 m^2 of the surface area.



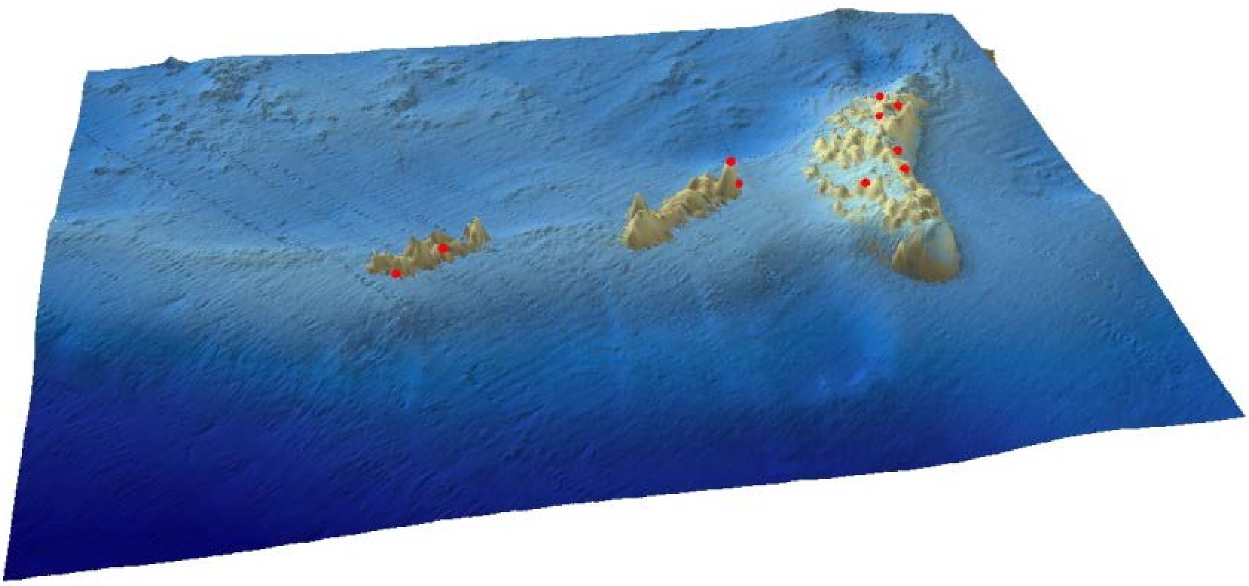


Figure 10. Anchor sites used for data collection on the new boulders.

Positions and depth of individual sampling stations are given in Appendix 2.

In a few cases, sampling was also done on the sandy/gravelly seabed very close the new reef structures or in-between the new boulders at the old seabed (*Figure 11*). In these cases the bigger 1/6 m^2 frame was used and the sampling procedure was the same as in 2007. Five such samples were taken at 9.2-10.2 m depth and 2 samples at 6.2 m depth.

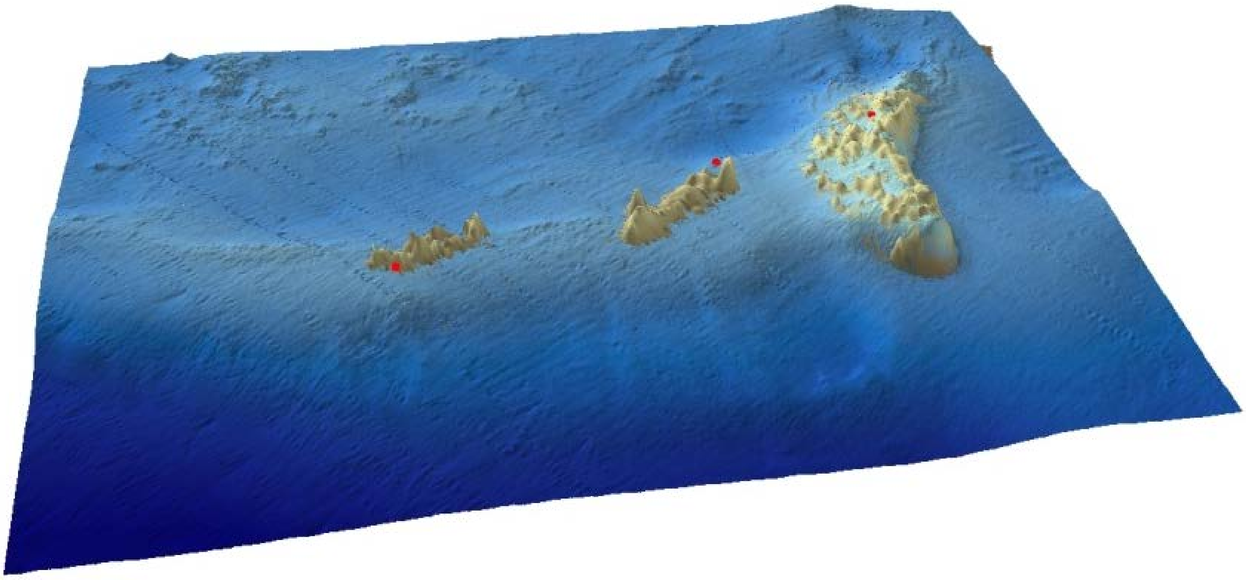


Figure 11. Anchor sites for sampling on gravely-sandy seabed.

In addition to the sampling at Læsø Trindel, three samples (0.1 m^2) were taken on smaller boulders (app. diameter of 40-50 cm) at the reef Per Nilen at 9 m water depth (*Figure 1*). The anchor position was 5722,498 N and 1102,498 E. This reef is less exposed lying closer to the island Læsø and sheltered to the west by a sand bar from Læsø to the tiny island Nordre Rønner.

The samples at Per Nilen represented more or less the whole surface area of the individual stone and as the reef was made up by a dense mixture of different sizes of stones piled onto each other, it was assumed that the extrapolation of biomasses and fauna abundance from frame size of 0.1 m^2 to 1 m^2 seabed was equal to a multiplication with a factor 10.

On deck all samples were immediately preserved in 4 % formaldehyde buffered with borax.

2.2.3 Laboratory procedures

In the laboratory the collected samples were split into 4 different fractions before species identification and quantification.

1) Algal species with sessile epizoa

2) Smaller mobile or detached animals, (1 mm-1 cm)

3) Larger mobile or detached animals > 1 cm

4) Stones (from gravely-sandy samples), fixed area subsample.

In fraction 1, 2 and 4 further subsampling was done in most of the samples. Subsample size was determined by moist weight. Large brown algal plants were cut in pieces with a scissor and mixed before subsampling. Laminaria hapters were also fractioned. Smaller algal individuals were torn in smaller pieces and mixed before subsampling. From each of these subsamples smaller mobile or detached animals were sorted out and pooled for identification and enumeration. A 1 mm sieve mesh was used throughout to catch them.

In samples dominated with gravel, from the sandy-gravely samples, subsamples of 25 % were taken both in 2007 and 2012. In samples taken on boulders in 2012 subsamples of 50 % were taken except in five cases where the whole sample was examined (MT 2-6) and in one case (B10-5) 70 % of the sample was examined.

Before subdivision and fractioning large mobile and detached animals were collected and measured for the whole sample.

Total ash-free dry weight of each species or higher taxonomic group, from the subsample or whole sample, was measured with 0.0001 g accuracy, though with grosser weight in the case of some of the larger species, especially the large brown algae and hapters. Abundance of free living species was counted.

In gravely-sandy samples 250 cm^2 of surface area of stones was studied using stereo microscope for identification of encrusting and tiny species generally not present in the other fractions. If stones were few all available area was investigated. Species identified on stones are mainly used to give a fulfilling picture of the species diversity and not quantified further.

To calculate the ash-free dry weight each species, or higher taxonomic group, sample was first dried in an oven at 105 °C for 24 hours and then weight measured. Afterwards, the sample was burned at 505 °C for 12 hours then weight measured again. The ash free dry weight was calculated by subtracting the ash weight from the dry weight. If subsampling had been used, the weight and abundance was adjusted accordingly.

The total area of the two Bryozoan species *Electra pilosa* and *Membranipora membranacea* covering the algal vegetation in each subsample was estimated. An area/ash free dry weight ratio of 0.0020 g/cm^2 was estimated based on 4 subsamples. Weights of the two Bryozoan species were then calculated based on estimated area in the samples. The estimated weight of the two Bryozoan species was then subtracted from the red and brown algal species on which they were growing.

In some cases selected species have been kept conserved and added to the species collection at Aarhus University as reference material. In these cases their weights have been added up or estimated from similar weighted specimens.

2.2.4 Estimation of biomasses and abundances on seabed on the new boulders

Samples collected by the 1/6 m^2 frame on the gravely-sandy seabed were all converted to numbers and biomasses per m^2 multiplying with a factor 6.

Estimation of species numbers and biomasses on the new large boulders was based on a number of assumptions:

- Algal and fauna are only present of the top boulder layer
- Boulders are all round and lay side by side with wholes in-between equal to an area reduction of 27,3 %.
- 1/6 of all boulder surfaces are in contact with other boulders or the seabed and for this reason assumed without biota
- The samples of the top of the boulders represent 1/6 of the boulder surface
- The samples of the side of the boulders represent the remaining 4/6 of the boulder surface.

An idealized circular boulder will have a 3.14 factor (phi) larger surface area that the area covered by a square with a size length like the diameter. Using the assumption mentioned above the sample on top of boulders (Ts) represent 1/6 of the overall boulder areal and the sample of the side of boulders (Ss) represent 4/6; then biomasses (BM) fauna abundances (FA) per m^2 seabed can be calculated as:

$$BM/FA = Ts \times 10 \times 3{,}14/6 \times 1 + Ss \times 10 \times 3.14/6 \times 4$$

2.3 Sampling of fish and shellfish fauna

The sampling program was conducted from April to October in 2007 (Before) and 2012 (After). The different activities are described in detail below. The main sampling was conducted at the central area of the Læsø Trindel shallower than 10 m. This area was subdivided in three areas: the central shallow part of the reef with depth between 2-6 m, the area West of the central part with depth between 6-10 m and the area East of the central part with depth between 6-10 m. For the trap fishery for lobster and crab the deeper surrounding area with depth from 10-15 m was also included. The surveys were conducted in co-operation with local fishermen either from chartered fishing vessels or from DTU Aqua research vessel "Havkatten" (June 2007 only).

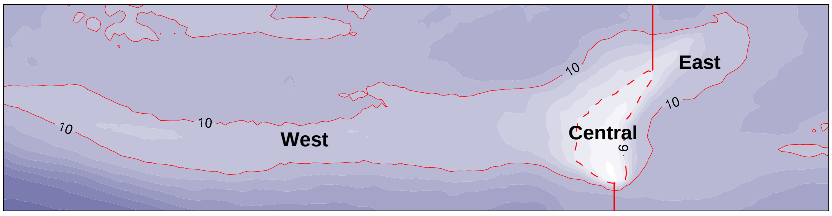


Figure 12. The main sampling area at Læsø Trindel with the three subareas central, East and West

Fish abundance was studied in surveys in April and June 2007 and 2012. In April, the larger sized fish fauna with focus on adult cod (*Gadus morhua*) was assessed using single-meshed gillnets. In June, juvenile and adult fish fauna in general were assessed using multi-meshed gillnets and fyke nets in the central Læsø Trindel area. The single meshed gillnet used in April had a mesh size, height and length of 70 mm, 1.6 m and 52 m (length of float line) respectively. The multi-meshed gillnets used in June had mesh size panels of 11, 14, 19, 24, 31, 41, 53 and 70 mm. All panels were 1.5 m high. The panels 11, 14, 19, 24, 31, 41 mm had a length of 6 m, the 53 mm panel was 12 m and the 70 mm measured 52 m. The multi-meshed gillnets were combined at random except for the 70 mm which was always placed at the start or end. Each mesh size panel was separated by 1.8 m wide window (float and sink line). The fyke nets were mounted with a mesh size of 18 mm and had a height of 42 cm and a 6.5 m leader. Gillnets were deployed in the afternoon or evening and retrieved the following morning (fishing time ~ 12 hours) while fish traps were deployed in the afternoon and fished for 2 days (fishing time ~ 48 hours). Catch was identified to species and total length of each fish measured to nearest 0.5 cm below and weighed.

Lobster (*Homarus gammarus*) **and brown crab (***Cancer pagurus***)** abundance were estimated from early summer to autumn using traps. The traps were Scottish type lobster/crab trap with the dimensions 66 × 47 × 42 cm and baited with salted flounder (*Platichthys flesus*). Two traps were set together attached by 18 m rope. The traps was set 4 times each period and fished for 3-4 days each time. Catch was identified to species, sexed and measured to 0.5 cm below. Thorax length was measured for lobsters and total carapace width for crabs.

Catch in numbers of fish and lobster/crabs were analysed using general linear effect models. Fish were analysed for the groups "Cod" (all species in the family Gadidae), “Wrasse” (all species in the family Labridae), “Flatfish” (all fish in the order Pleuronectiformes) and “other” which were all other fish species.

Fish catch data was +1 log10 transformed and followed a normal distribution and was analysed in proc glm in SAS, while catch in numbers of crab and lobster followed a negative binomial distribution and was analysed in proc genmod in SAS. We analysed for main and interactions effect of Before (2007)/After (2012) and the subdivided areas.

Analyses of feeding habits for key fish species was conducted in October 2007 and June and October 2012. Key fish species were defined as cod (*Gadus morhua*), goldsinny wrasse (*Ctenolabrus rupestris*) and saithe (*Pollachius virens*) (saithe was only caught in 2012). Multi-meshed gillnets were set at the same stations that were studied for abundance and biomass of benthic fauna (“Area V-M”). Gillnets were deployed just before sunset and retrieved approximately 2 hours later. An iron chain was towed close to the fishnets just before retrieval in order to frighten inactive fish into the gillnets. To prevent stomach decomposition, gillnets and their catches were immediately placed on ice in the boat. The fish were frozen to minus 18 ºC within 2-4 hours after catch and transported to the laboratory. After 1-2 months fish were defrosted, length measured and wet weighed. The liver was removed and wet weighed. The gut (in cod defined as the digestive to the pylorus sacs, while for goldsinny wrasse defined as the entire digestive tract) was removed and conserved in 70 % ethanol. Eviscerate fish and liver was dried at 60 ºC for 72 hours and reweighed. Gut contents were examined under a binocular microscope and dietary items were identified to the lowest taxonomic group possible. Each dietary item for each individual was recorded and measured for total or partial length and width in an image analysing system. The level of decomposition of the prey items was assessed on a scale from one to three where one was no signs of digestion and three was almost digested. Weight of prey items on digestive scale 1 and 2 was estimated by a calculation of volume assuming a cylinder shape of the prey items and a subsequent conversion to ash free dry weight (AFDW) using the conversion factors on order levels by Ricciardi & Bourget (1998) and Larson (1986). The used factors are listed in *Table 1*. Prey items were grouped accordingly to the taxonomical phylum and class. Crustaceans/Malacostraca were furthermore subdivided accordingly to their taxonomical order and family (suborder if it could not be identified to family level).

Table 1. Conversion factors from wet weight (WW) to ash free dry weight (ASFW) on different prey items groups.

Prey group	WW to ASFW
Annelida-Polychaeta-	0.16
Annelida-Polychaeta-Phyllodocida	0.16
Arthropoda--	0.16
Arthropoda-Arachnida-	0.16
Arthropoda-Malacostraca-	0.16
Arthropoda-Malacostraca-Amphipoda	0.16
Arthropoda-Malacostraca-Brachyura	0.17
Arthropoda-Malacostraca-Decapoda	0.17
Arthropoda-Malacostraca-Isopoda	0.14
Arthropoda-Malacostraca-Mysida	0.16
Arthropoda-Maxillopoda-	0.16
Arthropoda-Maxillopoda-Cyclopoida	0.16
Arthropoda-Maxillopoda-Harpacticoida	0.16
Arthropoda-Ostracoda-	0.16
Bryozoa--	0.11
Bryozoa-Gymnolaemata-Cyclostomatida	0.11
Chordata-Actinopterygii-Perciformes	0.16
Cnidaria-Hydrozoa-Hydroida	0.30
Echinodermata-Asteroidea-	0.11
Echinodermata-Echinoidea-Echinoida	0.11
Mollusca--	0.06
Mollusca-Bivalvia-	0.06
Mollusca-Bivalvia-Mytiloida	0.06
Mollusca-Gastropoda-	0.08
Mollusca-Gastropoda-Mesogastropoda	0.08
Mollusca-Polyplacophora-Phyllodocida	0.08
Nematoda--	0.20
Nemertea--	0.20

Weight was expressed in mg and converted to log10 +1 prior to statistical analysis. Difference in weight in stomach of prey items for the different fish species were analysed by a general linear effect model that was step wised reduced:

$$(\log(Prey_{weight} + 1)) = Period + fish\ length + Period \times fish\ length \quad \text{Equation 1}$$

where $Prey_{weight}$ is prey weight in mg, *Period* is before - after restoration of the reef and fish length is the total length of the investigated fish, *Period × fish length* represents the interaction effect between Period and Fish length.

Abundance of prey items in guts will be cross correlated to available food items obtained by the benthic fauna sampling conducted in June to analyse feeding ecology and food web dynamics of the key species.

Behavior and migration of cod and lobster was studied by catching fish and lobsters in fyke nets and traps and releasing them with acoustic telemetry tags. Acoustic coded tags (Thelma LP9) were implanted in cod and placed on lobsters as described by Moland et al. (2013) The LP9 tag has a guaranteed battery life time of 1 year. A total of 18 cod and 10 lobsters in 2007 and 16 cod and 7 lobsters in 2012 were tagged. Each tag had a unique code that was transmitted every 1 to 3 min. The acoustic signals from the tagged individuals were picked up by an array of receiver buoys that were deployed in a grid covering the Læsø Trindel area. In 2007 the grid consisted of 10 buoys while the number of buoys was increased to 22 in 2012 due to the more complex bottom topography with a higher shading effect after the restoration. Data was downloaded from receivers on the 18. December 2007 and 3-4 June 2008 and data on tagged fish in 2012 will be downloaded in summer 2013.

3 Results

3.1 Hydrographical conditions at Læsø Trindel

The average summer (June-September) and winter (November-February) salinity from the two nearby hydrographical monitoring stations 1007 and 1008 sampled as part of the National monitoring programme is shown in *Figure 13*. At 6 m water depth the salinity varies from a summer average of around 23.5 psu to a winter average of approximately 28-29 psu. At 9 m depth the variation between summer and winter salinity is still pronounced. CTD profiles on West-East transect intersecting Læsø Trindel also showed a depth gradient in temperature and salinity 16-18 °C and 19 psu salinity at the surface and at 10 m, 14-15 °C and 30 psu salinity. Surface water masses at the western part of the transect was 1-2 °C warmer compared to the eastern part but otherwise water masses were relatively uniform across Læsø Trindel (*Figure 13*).

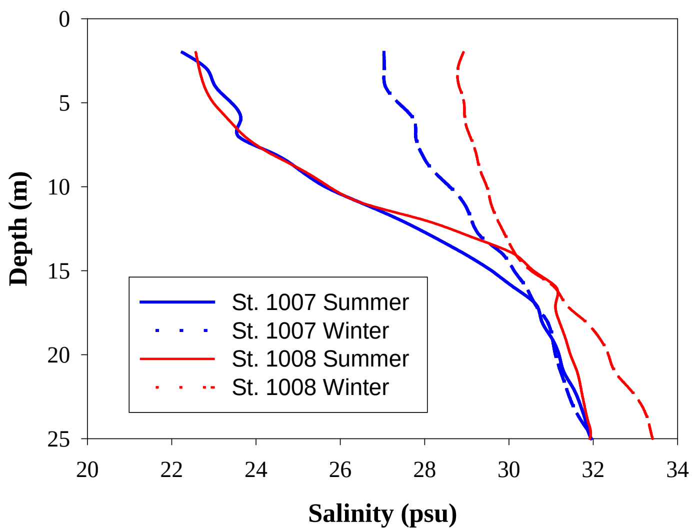


Figure13. Average summer and winter salinity profiles at the hydrographical station 1007 and 1008 sampled as part of the National Marine Monitoring Programme. The values are calculated based on a yearly sampling program over 15 years from 1998.

3.2 Biological diversity

The suction sampler investigation in 2007 on the sandy-gravely seabed revealed 186 taxonomic distinct taxa in those areas where the nature restoration was intended to take place. Most of those taxa were identified to species level. Most taxa were found on the shallow part of the reef (140) with the highest amount of stones but 23 % of the taxa were only identified on the deep stations at the middle and western part of the reef area at 9-10 m depth (*Table 2* and *Figure 14*). In both depth intervals 2.3 m^2 seabed were sampled.

The species diversity in each of the samples collected by suction sampling was highly variable on the deep stations in the western and middle parts of the reef ranging from 60 distinct taxa per 0.1 m^2 to just 3. Half of the samples showed less than 10 taxa per 0.1 m^2. On the shallow stations the diversity ranged from 35 to 63 distinct taxa per m^2 and in half the samples between 50 and 57 taxa were identified.

Table 2. Total number of identified distinct infauna, epifauna algae and fish taxa in the 2007 and 2012 investigations. The taxa are separated into different taxonomic groups identified from the three selected depth intervals and total for all sampling stations for each year. Fauna taxa are separated in two groups: one representing strictly sessile living forms and the other representing organism with some motility.

	2007			2012			
	6 m	9 m	All depths	3 m	6 m	9 m	All depths
Epifauna							
Sessile fauna							
ANTHOZOA	0	0	0	2	2	3	3
ASCIDIACEA	0	0	0	0	2	2	3
BRYOZOA	15	9	19	6	8	22	24
CRUSTACEA	4	2	4	3	3	2	3
ENTOPROCTA	2		2	0	0	0	0
HYDROZOA	13	7	15	9	11	12	15
POLYCHAETA	1	0	1	1	1	2	2
PORIFERA	1	1	1	3	1	4	4
Motile fauna							
ARACHNIDA	0	0	0	0	1	1	1
BIVALVIA	3	2	3	4	5	6	7
CRUSTACEA	16	18	22	11	21	24	29
ECHINODERMATA	2	2	3	1	3	6	6
GASTROPODA	8	9	13	2	5	11	11
INSECTA	0	0	0	0	0	0	0
NEMATODA	1	1	1	1	1	1	1
NEMERTEA	1	1	1	0	1	0	1
PANTOPODA	0	1	1	3	3	4	4
PISCES				0	2	1	2
POLYCHAETA	12	10	16	5	6	10	10
POLYPLACOPHORA	1	0	1	0	0	1	1
Infauna							
Sessile fauna							
POLYCHAETA	0	0	0	0	0	0	0
Motile fauna							
ANTHOZOA	0	1	1	0	0	0	0
BIVALVIA	3	4	7	0	1	3	3
CEPHALOCHORDATA	0	1	1	0	0	0	0
GASTROPODA	0	0	0	0	0	2	3
OLIGOCHAETA	1	0	1	0	1	0	1
POLYCHAETA	6	11	14	0	0	6	6
Macrophytes							
Chlorophyta	4	2	4	1	2	4	4
Phaeophyta	14	11	16	9	15	18	21
Rhodophyta	32	29	39	20	29	46	48
Sum epifauna	80	63	103	51	76	112	127
Sum infauna	10	17	24	0	2	11	13
Sum algae	50	42	59	30	46	68	73
Total diversity	140	122	186	81	124	191	213

The overall number of identified distinct taxa on the boulders in 2012 was 213. The largest number of taxa was found in the deepest depth interval and the smallest number on the shallowest part. However, the number of 0.1 m^2 frames investigated also differs considerable from 8 in the shallow water stations, 30 from 4.5 to 7.5 m to 24 in the deepest part from 7.5-10 m.

A number of infauna taxes were registered in samples taken on the gravely-sandy sediment before the restoration took place (*Figure 13*). Examples are the polychaete *Pisione remota* and the primitive fish species *Branchiostoma lanceolatum* that is typically found in rather course sand in Kattegat. However in-fauna species were also surprisingly registered in samples from boulder surfaces, especially from the deepest investigated interval. This indicates that those species might find a niche to survive in dense algal cover.

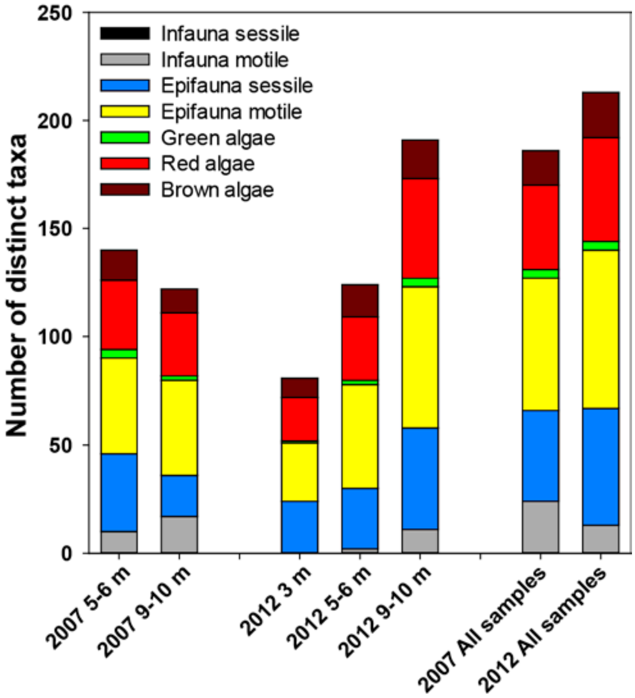


Figure 14. Total number of macro algae, fish, and sessile and motile fauna species identified from the three investigated depth intervals and total for all depth intervals for each year. Fauna species are separated in four groups sessile/ motile and infauna/epifauna.

3.3 Biomass and abundance of flora and fauna

3.3.1 Biomass

Restoration of the reef has so far resulted in an overall increase in biomasses of almost 6-8 fold in the two depth intervals 5-6 m and 9-10 m.

Brown and red algal species made up the majority of biomasses in 2007. The two algal groups were still dominant in 2012 but the anthozoan, *Metridium senile*, was found with very high biomasses as well (*Figures 15* and *16*). *M. senile* was not recorded at all on the reef before the restoration project was initiated.

Figure 15. New boulder with red and brown algal vegetation and the sea anemone *Metridium senile* in August 2012. Photo: Karsten Dahl

In 2007, the bryozoan *Electra pilosa*, living epiphytic on macrophytes, completely dominated the fauna biomass. *Electra* was also common in 2012 but crustaceans and gastropods were now found with considerably higher biomasses.

Opportunistic species like *Chorda filum* (*Figure 16*), *Ectocarpus silicuosa* (*Figure 17*) and fast growing epiphytic species like *Ceramium virgatum* and *Polysiphonia stricta* made up most of the biomass at 5-6 m depth in 2007 before the restoration took place. Juvenile kelp species were also present frequently. In some frames where one or a few large stable stones were present, larger specimens of *Laminaria digitata*/*hyperborea* and *Desmarestia alata* were found together with other typical perennial species like *Delesseria sanguinea*, *Phyllophora pseudoceranoides* and *Ahnfeltia plicata*.

Four of the frames taken in 2007 at the deeper Western part of the reef and three at the middle part of the reef were totally without vegetation due to lack of suitable substrate and two more were also nearly empty. The other samples all included vegetation and in two cases with high biomass due to the presence of large stable boulders as substrate. In general, if vegetation was present at 9-10 m depth then it was almost without typical opportunistic species. In frames with good substrate condition, species like *Desmarestia viridis*, *Desmarestia aculeata*, *Laminaria digitata/hyperborea*, *Laminaria saccharina*, *Phycodrys rubens*, *Phylophora pseudoceranoides*, *Delesseria sanguinea*, *Rhodomela confervoides* made up the vast majority of the algal biomass together with a smaller amount of *Polysiphonia* species growing as epiphytes on other red algal species. *Figure 20* shows a typical community on a large boulder at 9.5 m depth at Læsø Trindel.

Biomasses of the brown algae species *Desmarestia viridis* were very dominant in 2012 at 3 m and 5-6 m depth interval. At 9-10 m depth the dominance of this species was taken over by brown kelp species (*Saccharina* and *Laminaria* species) of which many were still juveniles. The red algae species *Phylophora pseudoceranoides* made up a considerable biomass at all three depth intervals in 2012. *C. filum* was not registered at all on boulders in 2012 and *Ectocarpus siliquosa* was only scarcely present in the samples.

Figure 16. Average ash free biomasses per m^2 and distributed on taxonomic groups sampled by suction-sampler at two depth intervals in 2007 and three depth intervals in 2012.

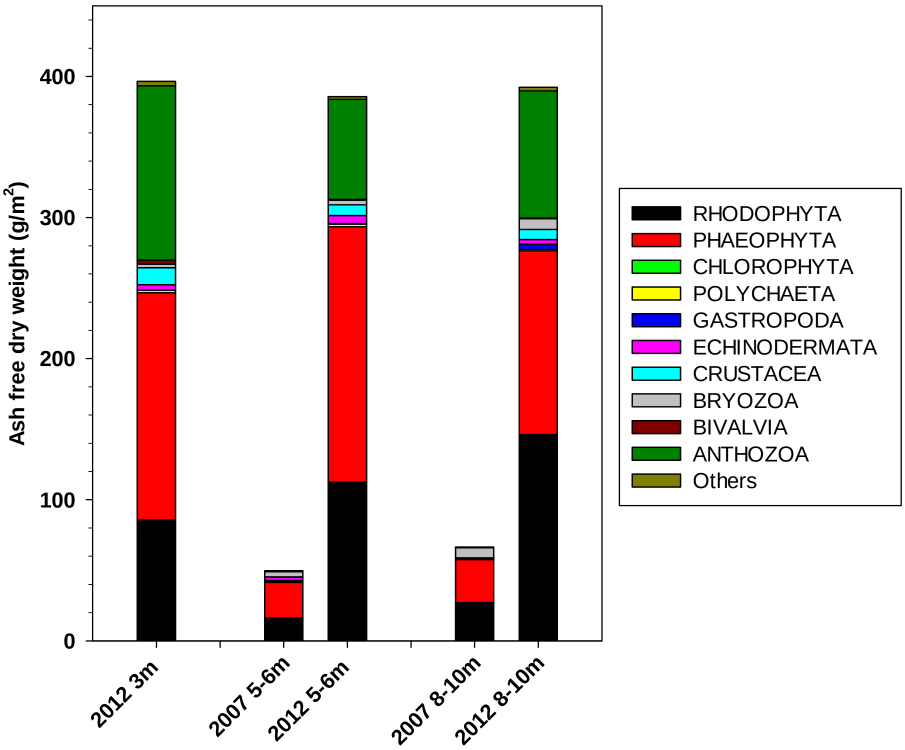


Figure 17. Average ash free biomasses per m^2 and distributed on the most important species/ species groups sampled by suction-sampler at two depth intervals in 2007 and three depth intervals in 2012.

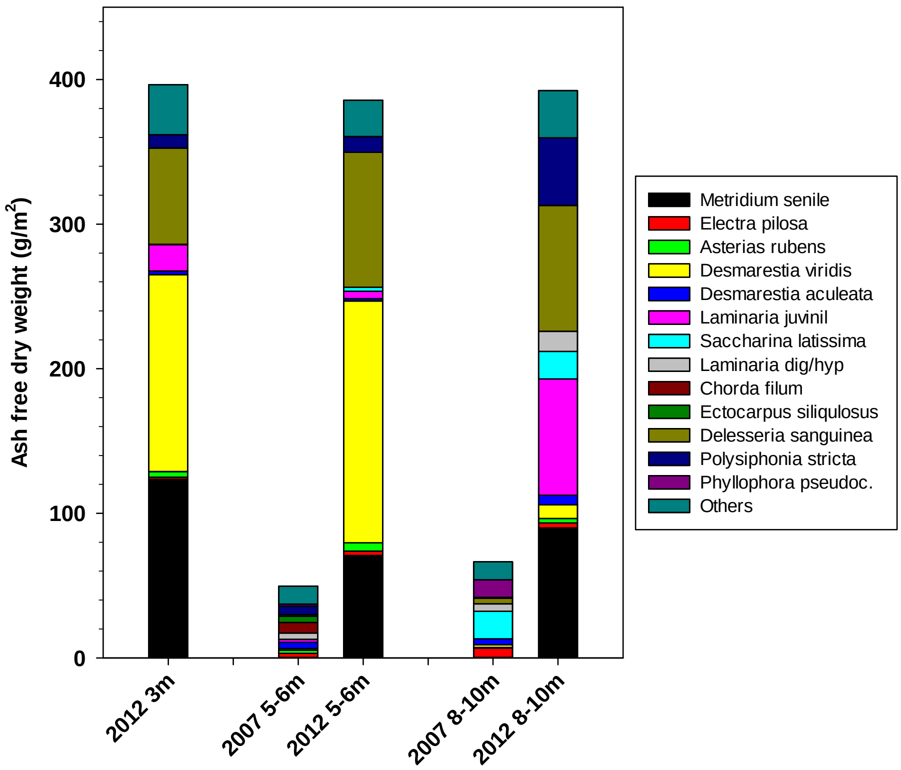


Figure 18. *Chorda filum* growing at Læsø Trindel at 6 m depth in June 2007.
Photo: Karsten Dahl

Figure 19. The epiphyte *Ectocarpus siliquosa* growing on *Desmarestia aculeata* on smaller stones at Læsø Trindel at 6 m depth in June 2007.
Photo: Karsten Dahl

Figure 20. Large boulder with high biomasses of macroalgae. The species assemblage consists of *Laminaria digitata*/*hyperborea*, *Dilsea carnosa* (which was not sampled with the frames), *Delesseria sanguinea* and *Brongniatella byssoides*. The Bryozoan *Electra pilosa* covers large parts of the Laminaria and Delesseria leaves.
Photo: Karsten Dahl

3.3.2 Abundances

The overall number of individual species increased considerably at Læsø Trindel at the newly established boulder reef compared with the situation in 2007 (*Figure 21*). The increase was more that 4-fold at 5-6 m depth and more than 6-fold at 9-10 m depth. Bivalves were relatively more dominant in the investigation in 2007 whereas crustaceans and to some extend gastropods and anthozoans have taken over in the 2012 investigation.

In 2007 *Mytilus edulis* was the absolute dominating species at the two investigated depth intervals, but *Asterias rubens* and nematodes were also numerous. The dominating Crustaceans in 2007 were *Jassa falcate*, *Calliopius laeviusculus* and mainly on the deep station *Caprella* (*Figure 22*).

The abundance and relative dominance of species was very different in 2012. *Mytilus edulis* was still numerous although less in numbers compared to 2007. However a much larger range species contributed to the large abundance. Six different Crustacea species were important and there was a pronounced shift from dominance of *Jassa falcate* on the shallow stations to two *Caprella* and the gastopod species *Pusillina sarsii.*

The relative high numbers of *Mytilus edulis* in 2007 as well as in 2012 were newly settled individual typically only a few mm long and with very low biomasses. The presence of starfish (*Asteriea rubens*) with higher biomass than *Mytilus* at the same stations indicated a very high mortality rate witch is also reflected in the fact that adult *Mytilus* is seldom found on reefs investigated as part of the national monitoring program (NOVANA) in open waters in Kattegat (Dahl pers com.).

Metridium senile was much more abundant on the shallow stations in 2012 compared to the two deeper investigated depth intervals. This difference was only to some extent reflected in the biomasses (*Figure 22*) indicating that a successful settlement of the sea anemone happened more quickly at the deeper stations.

The epifauna gastropod species *Lacuna vincta* was found on several stations in 2007 and in both investigated depth intervals but it was not identified at all in 2012.

Figure 21. Average abundance of individual fauna organisms sampled by suction sampler per m^2 distributed on larger taxonomic groups.

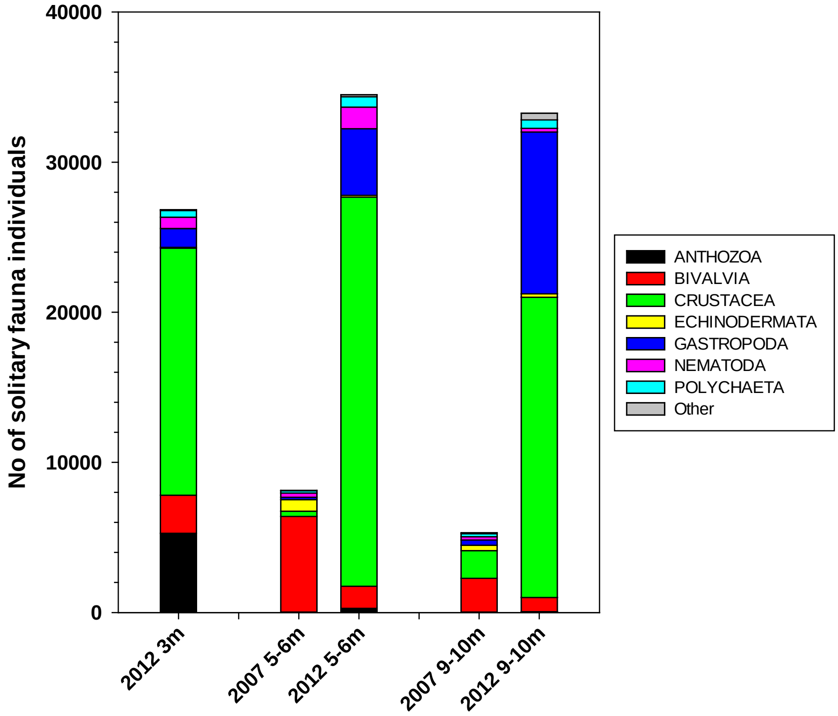
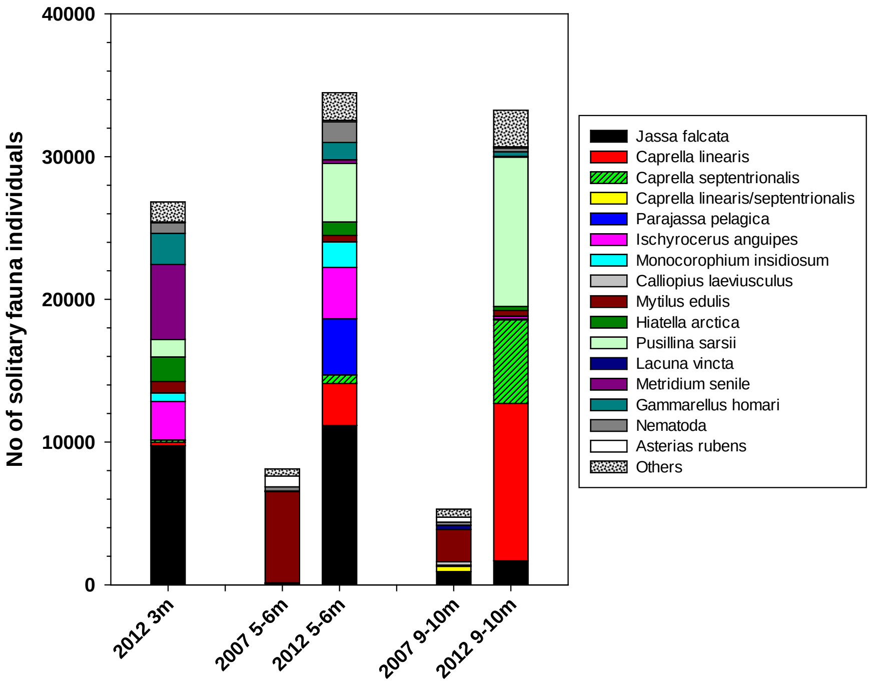


Figure 22. Average abundance of the 16 most abundant fauna organisms sampled by suction sampler per m^2 as well as the number of the remaining other species.



3.3.3 Biomasses and abundances achieved by the nature restoration project

It is possible to give an estimate of the overall gain in biomasses and abundances of species achieved by the project over the 4 years the new boulder reef has existed. This estimation is of course based on the assumption that the difference expresses an "added value" of the new reef and not year to year changes in biomasses. This estimation is done by calculating the difference in biomasses and abundances from 2007 to 2012 combined with knowledge of the depth distribution of the former seabed in 2007 and the area and depth distribution of the newly established boulder reef structures (*Figure 5*).

The overall gain of macroalgal vegetation is a bit more that 6 ton ash free biomass and the gain in bottom fauna is nearly 3 ton ash free biomass (*Table 3*).

Table 3. Estimation of fauna and algal biomasses on the seabed used for the reef project before the restoration (2007), after the restoration (2012) and the difference (extra) between the estimates, representing the gain in biomasses.

Depth interval	Area with new boulders	Fauna biomass (ton)			Algae biomass (ton)		
(m)	(m^2)	2007	2012	Extra	2007	2012	Extra
1.5-4.5 m	7125	0.05	1.07	1.01	0.30	1.76	1.46
4.5-7.5 m	11725	0.09	1.08	0.99	0.54	3.44	2.90
7.5-10 m	8500	0.08	0.99	0.91	0.49	2.35	1.86
Overall		0.22	3.13	2.91	1.33	7.55	6.22

The same calculation can be made for abundance of individual fauna species (*Table 4*). In this case the overall gain by the restoration is almost 700 million individual fauna organism.

Table 4. Estimation of abundance of individual fauna organism on the seabed used for the reef project before the restoration (2007), after the restoration (2012) and the difference (extra) between the estimates, representing the gain in abundance.

		Fauna abundance in mill.		
Depth interval	**Area with new boulders**	**2007**	**2012**	**Extra**
1.5-4.5 m	7125	57,92	191,21	133,29
4.5-7.5 m	11725	87,06	404,47	317,40
7.5-10 m	8500	45,18	282,79	237,61
Overall		190,16	878,46	688,30

3.4 Fish communities

3.4.1 Abundance

Cod abundance increased in the vicinity of the restored reef and was most evident in the shallow boulder reef area at 2-6 m depth (*Figures 24* and *25*). This was evident from both sampling methods: the gillnets and fyke nets. Furthermore, rock-affiliated fish belonging to the wrasse family showed a higher affinity to the shallow part of the reef (*Figure 23*) but the increase in abundance was primarily in the surrounding deeper areas (6-10 m) of the reef in the gillnet samples (*Figures 24* and *25*). Flatfishes declined in abundance after the reef restoration in the shallow part of the reef where the cavernous boulders were established. This was significant in the gillnet samples. For the remaining fish community, abundance was stable with no significant tendency.

Figure 23. Large number of different species of wrasses in the multi mesh gillnets in June 2007.
Photo: Claus Stenberg

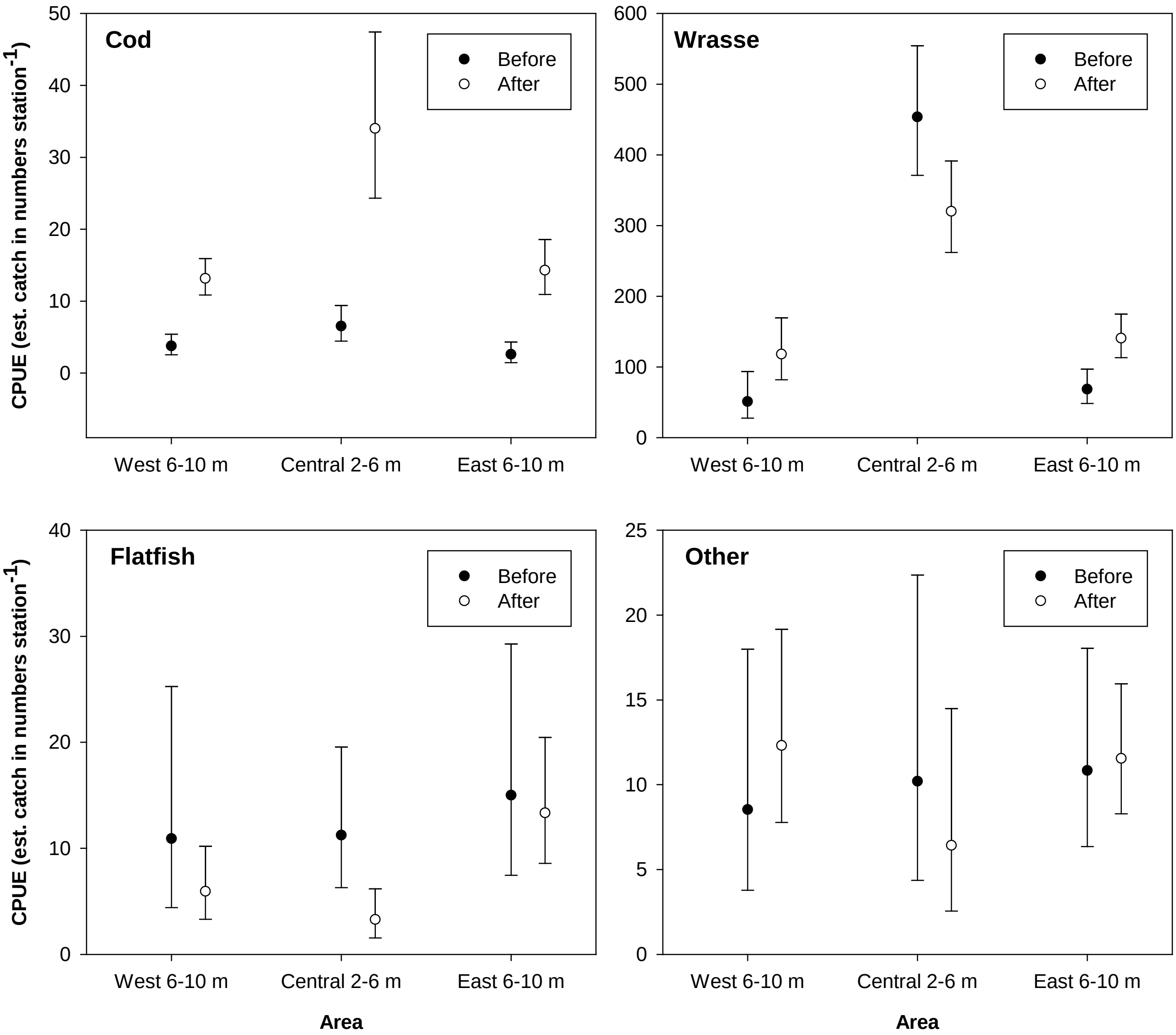


Figure 24. Catch per unit effort (CPUE) using gillnets for different fish groups Before and After the reef restoration and at different sampling depths and areas. Bars indicate 95 % CL.

Analyses of brown crab and lobster abundance estimated from the trap fishing showed that there was no significant effect of month or the "2-6 m" and "6-10 m" depth stratification within Læsø Trindel. Samples were therefore grouped into shallower than 10 m at Læsø Trindel (< 10 m) and deeper than 10 m outside Læsø Trindel (> 10 m). In this analysis we found a significant increase in the abundance of brown crab in both areas, most pronounced in the deeper area outside Læsø Trindel (> 10 m) (*Figure 26*). Lobster abundance was low both before (0.05 lobster/station) and after (0.038 lobster/station) the restoration and no significant change was observed ($p > 0.6$) (*Figure 27*).

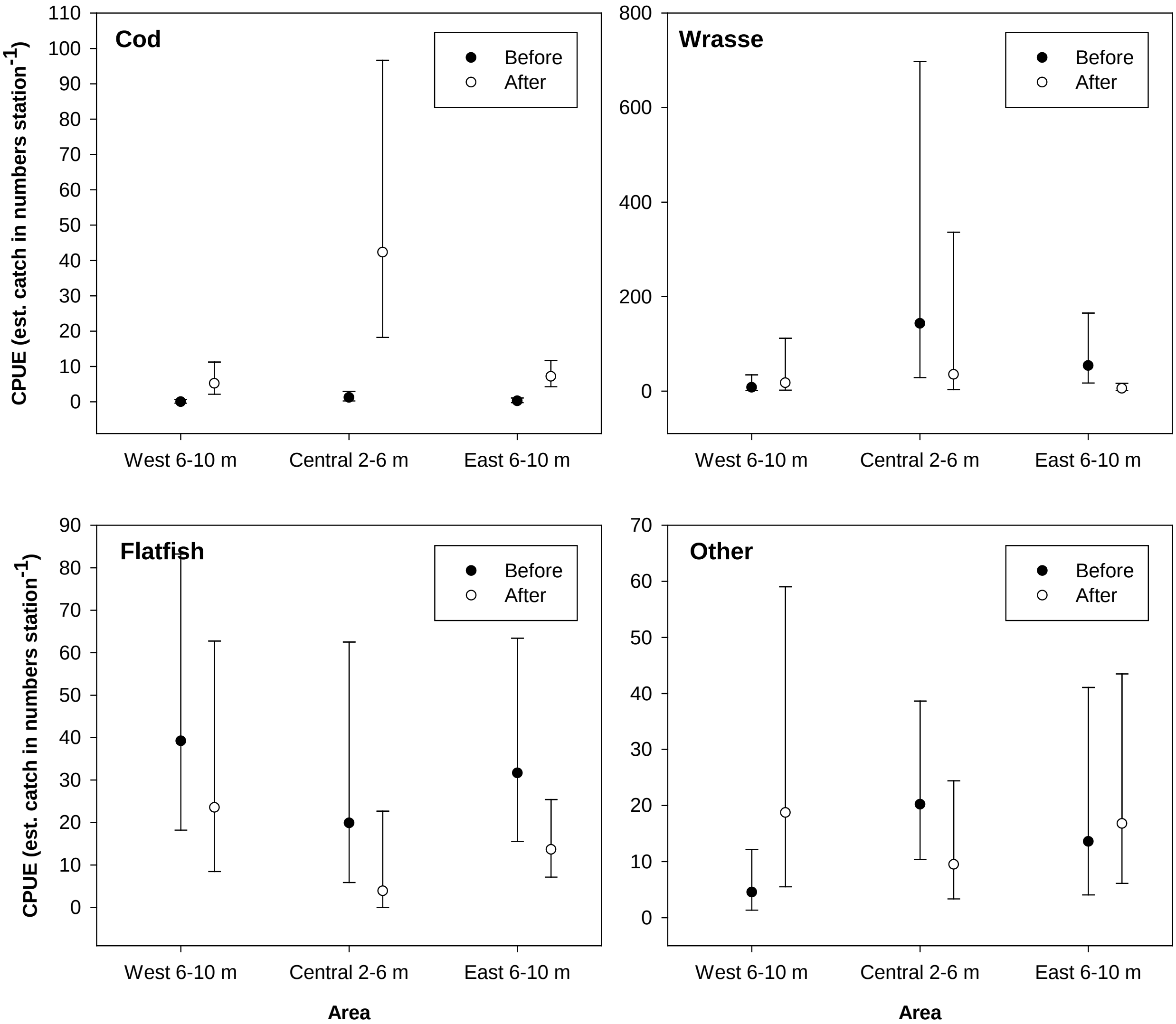


Figure 25. Catch per unit effort (CPUE) using fyke nets for different fish groups Before and After the reef restoration and at different sampling depths and areas. Bars indicate 95 % CL.

Figure 26. Catch per unit effort (CPUE) of brown crab (*Cancer pagurus*), using traps in 2007 (Before) and 2012 (After) at different depths intervals. Bars indicate 95 % CL.

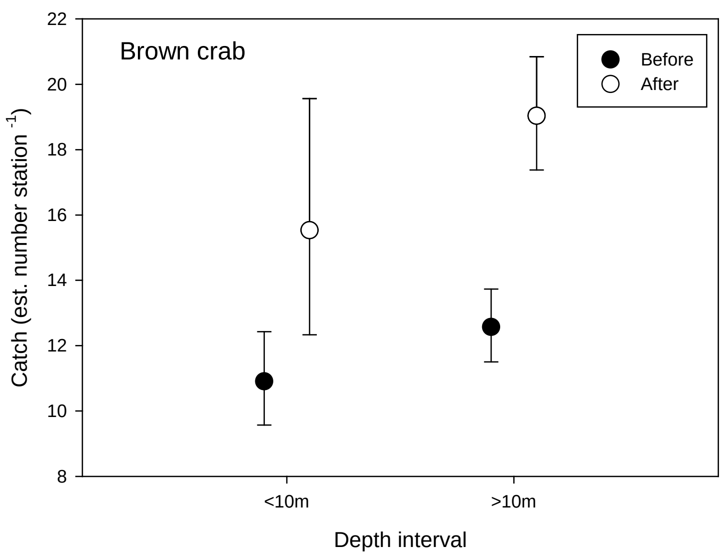


Figure 27. Lobster (*Homarus gammarus*) caught in the trap fishery in June 2012. Photo: Claus Stenberg

3.4.2 Fish communities and species composition

Number of fish species were 34 and 30 respectively before and after the reef was restored and thus remained at the same level. The fish community both before and after the restoration was dominated by species from the wrasse family. However, there were marked changes within the wrasse species in the period. Species such as goldsinny wrasse (*Figure 30*) increased several fold while corkwing ballan wrasse and small mouthed wrasse decreased. A marked increase in dominance was also seen for cod and the other gadoid, the saithe, which both became more frequent in both the sampling methods (*Figures 28* and *29*).

Figure 28. Relative occurrence of different fish species caught in the multimesh gillnets before and after the reef restoration.

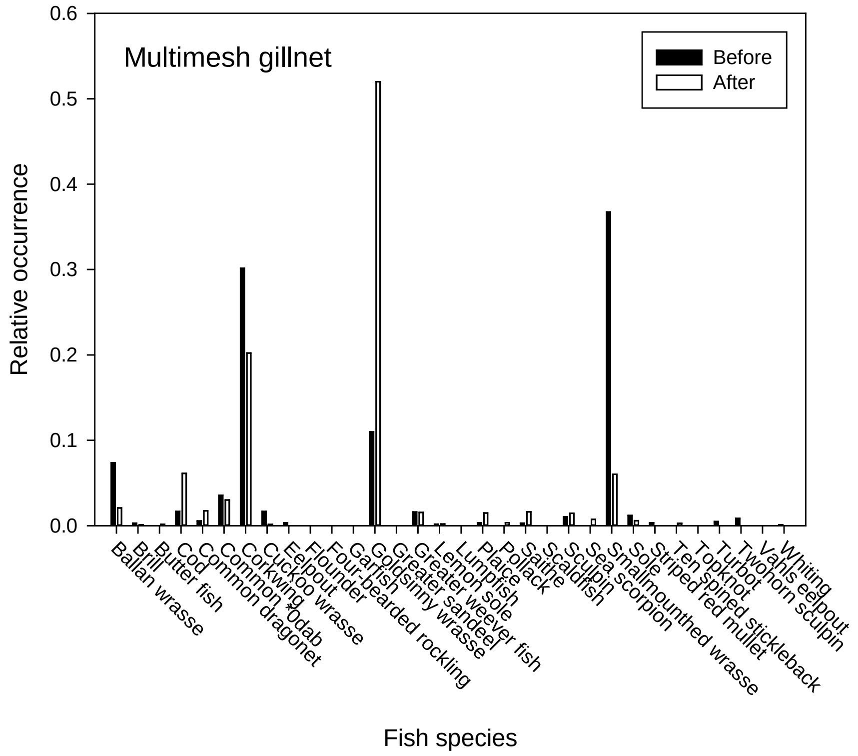


Figure 29. Relative occurrence of different fish species caught in fyke nets before and after the reef restoration.

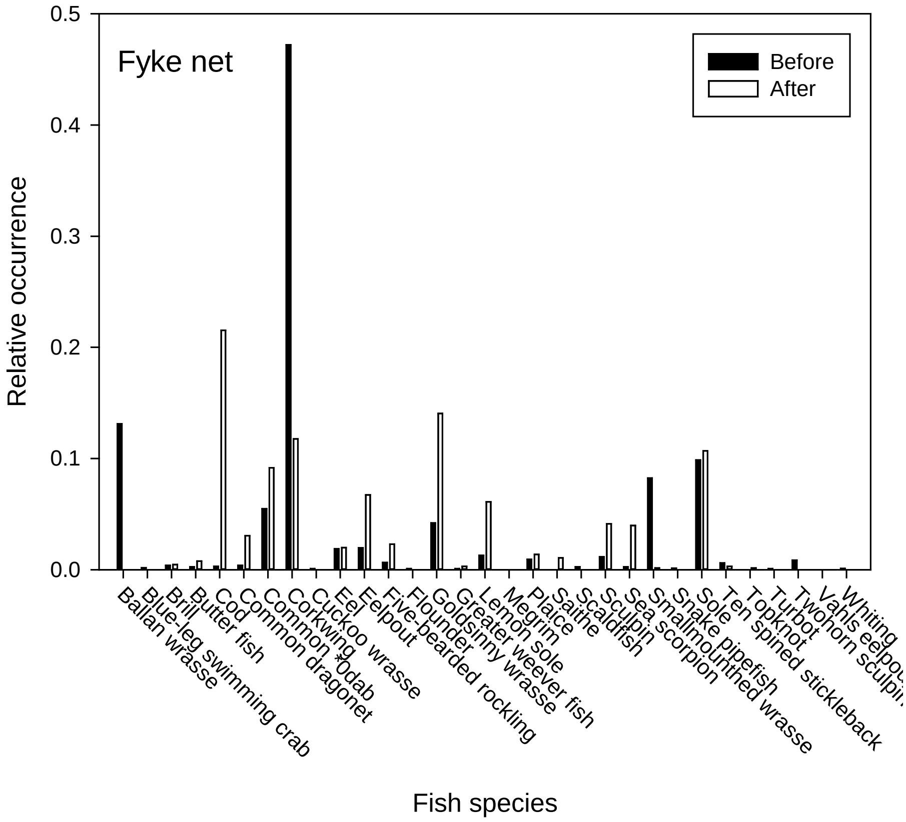


Figure 30. Goldsinny wrasses (*Ctenolabrus rupestris*) on the measuring board. Photo: Claus Stenberg

3.4.3 Fish stomach analyses

A total of 66 cod were sampled in October 2007, whereas in 2012, 60 cod were sampled in June and 37 in October (*Table 5*). Due to differences in stomach content between June and October, the BACI analysis was conducted only on the cod caught in October in 2007 and 2012. Saithe were only caught in 2012. A total of 82 specimens were analysed for stomach contents. A total of 62 goldsinny wrasse was sampled in 2007 and 11 in 2012.

Table 5. Number of cod, saithe and goldsinny wrasse sampled for the stomach analyses.

		< 20	20-30	> 30	total
Cod	2007 October	58	7	1	66
Cod	2012 June	27	28	5	60
Cod	2012 October	3	19	15	37
Saithe	2012 October	30	52		82
Goldsinny wrasse	2007 October	62			62
Goldsinny wrasse	2012 June	11			11

Cod with empty stomachs were only registered in October 2007 and constituted 1.5 %.

Crustaceans dominated in cod stomachs both Before and After the reef restoration (*Figure 31*). After the restoration, the dominance of crustaceans in cod stomachs became more pronounced. Fish, which has not previously been observed in the cod stomachs in the Before sampling, were evident in the After sampling.

Among the crustaceans, the main prey items were Gammaridae, which dominated more markedly after the reef restoration (*Figure 32*). A significantly higher biomass of crabs was also observed in the cod stomachs after the reef restoration.

Figure 31. Estimated average biomass of different prey phyla or classes in stomachs from cod sampled before (2007) and after (2012) the reef restoration.

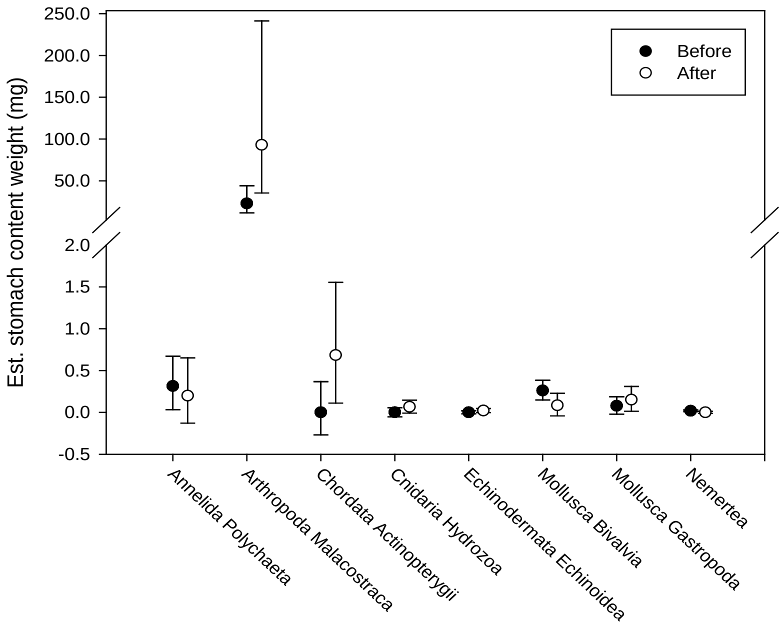
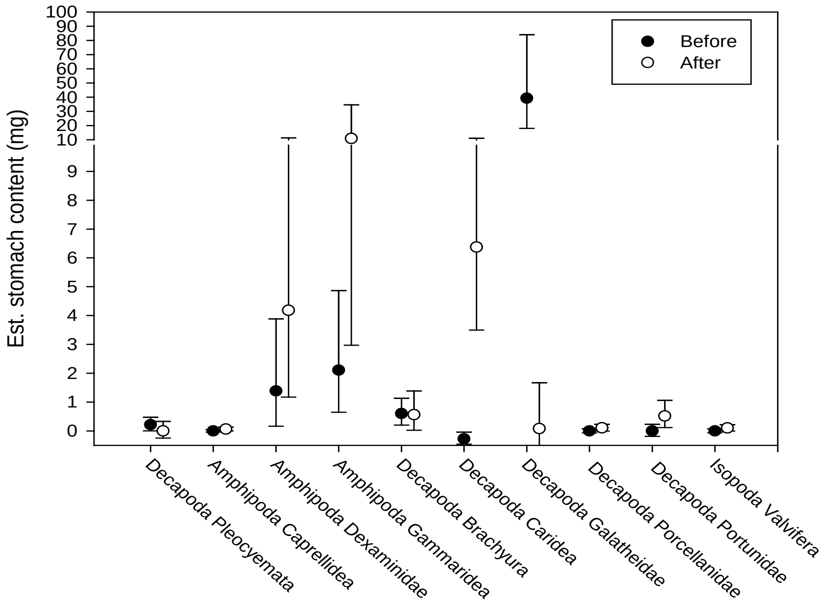


Figure 32. Estimated average biomass of different crustaceans in stomachs from cod sampled before (2007) and after (2012) the reef restoration.



A comparison of stomach contents of cod and saithe for stomachs sampled in October 2012 showed that cod had relatively higher content of crustaceans, while saithe fed primarily on fish (Chordata Actinopterygii) (*Figure 33*). Cod was observed to prey on a wide variety of fish species while saithe only preyed on sandeel (Ammodytidae) and horse mackerel (*Trachurus trachurus*) (*Table 6*).

Figure 33. Relative content (numbers) of prey items in stomachs of cod and saithe sampled in October 2012.

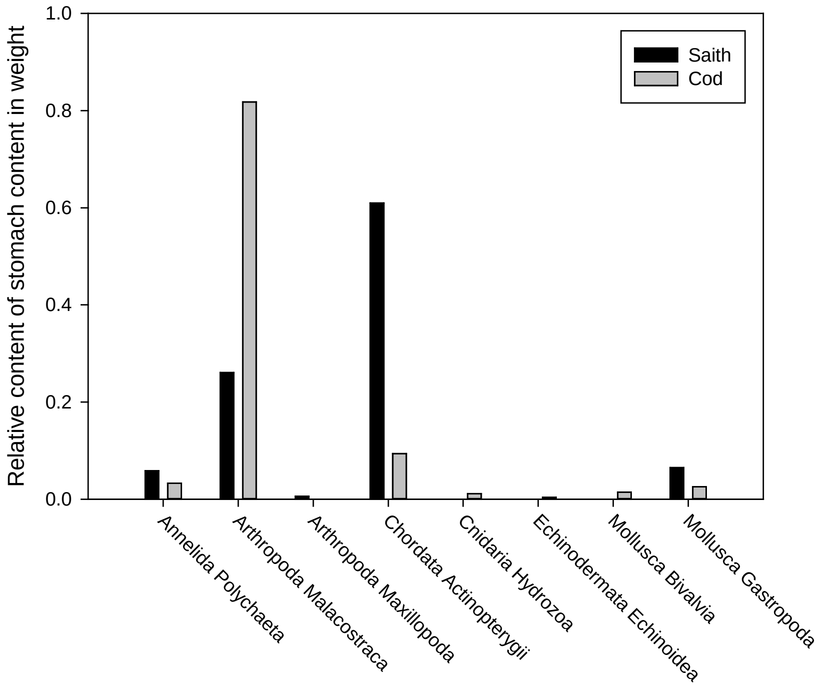


Table 6. Presence of fish prey items in cod and saithe stomachs after the restoration.

Prey		Cod	Saithe
Group	**Species**		
Perciformes Ammodytidae			x
Perciformes Callionymidae	Callionymus ssp.	x	
Perciformes Carangidae	Trachurus trachurus	x	x
Perciformes Gadidae	Gadus morhua	x	
Perciformes Labridae	Labrus ssp.	x	
Perciformes Pholidae	Pholis gunnellus	x	
Perciformes Zoarcidae	Zoarcea viviparus	x	

Content of polychaetes generally increased in the stomachs of goldsinny wrasses after the reef restoration, whereas there were on average slightly lower content of crustaceans (Malacostraca), although the differences were not significant (*Figure 34*). The biomasses of the other prey phyla or classes in the stomachs of goldsinny wrasses were similar before and after the reef restoration.

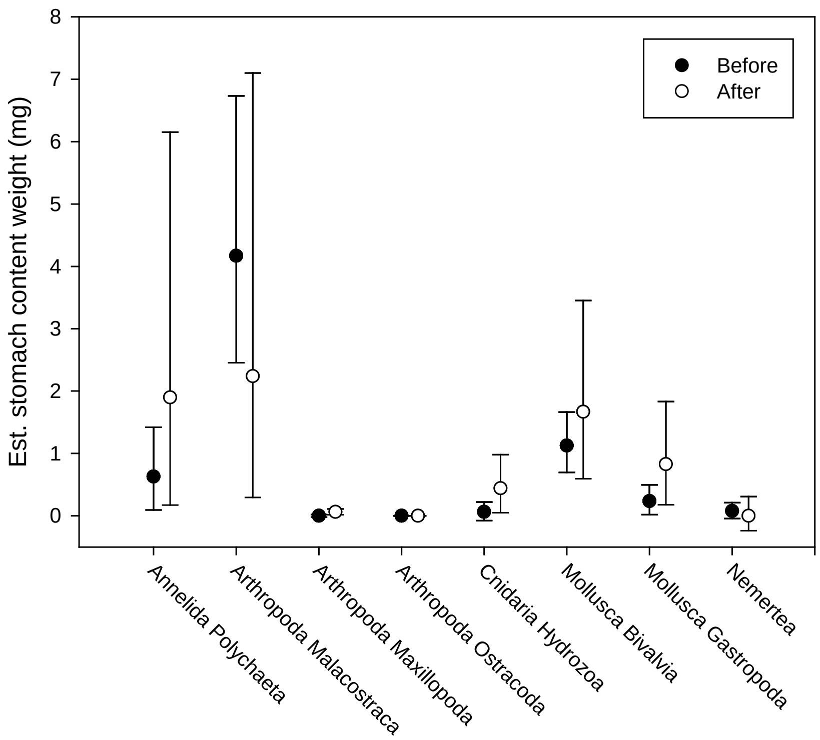


Figure 34. Estimated average biomass of different phyla or classes in stomachs from gold-sinny wrasses sampled before (2007) and after (2012) the reef restoration.

The analyses of the size distribution of all fish showed an increase in fish larger than 20 cm after the restoration (*Figure 35*). A closer look at the size distribution of the key species caught in the reef area showed that this was mainly due to a larger proportion of the larger cod juveniles, which aggregated around the shallow part of the reef after the restoration.

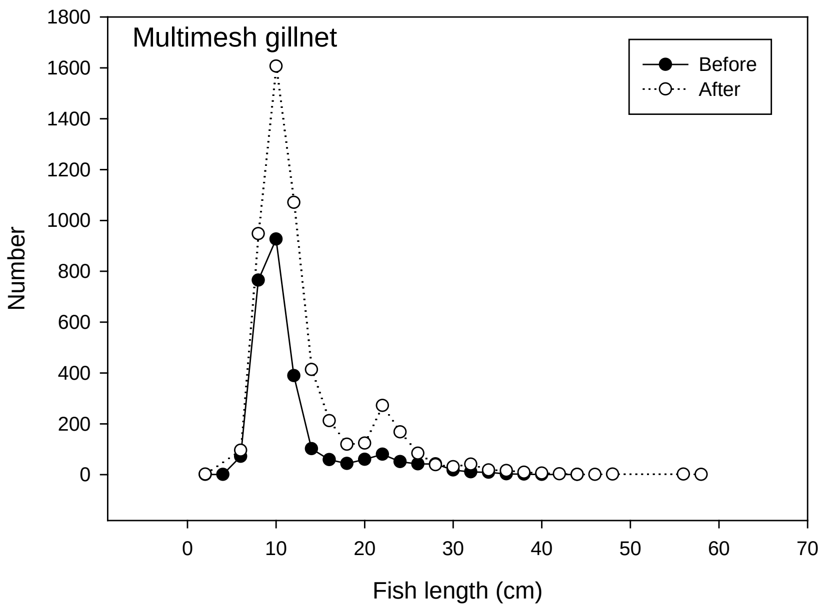


Figure 35. Length distribution of all fish combined in the Before and After samples.

4 Discussion and conclusion

The biodiversity in terms of species of flora, fauna and fish identified on Læsø Trindel in 2007 was not poor. The overall diversity on the reef in terms of identified distinct flora and fauna species was only slightly higher in 2012 compared to 2007, but the samples in 2007 comprised both epifauna and vegetation on typical hard substrate and infauna species collected on more gravely-sandy seabed.

The algal vegetation sampled within the frames in 2007 was on most occasions dominated by fast-growing opportunistic species or smaller individuals of perennial algal species. This indicates a reef with an unstable structure preventing perennials to develop and they remain in a state of constant renewal. However, the presence of scattered large stable boulders in the area before the restoration has most likely secured the relatively high species number and a species pool for colonisation of the new reef for those species with a local colonisation strategy. Is should be noted that the overall area sampled in 2012 was 33 % larger than the area sampled in 2007 and generally there is a correlation between species numbers and sample area.

A similar investigation with suction sampler on a natural boulder reef area has been done in Samsø Belt in approximately the same depth interval (Dahl et al. 2005). Samsø Belt is influenced by the outflowing Baltic water and is characterised by lower salinity. In this study we found 47 algal and 120 fauna species in samples covering an area of 3.6 m^2 in total on top of the boulders at the same depth intervals as the investigations at Læsø Trindel. The average biomasses were 1123 g ash free dry weight at 4 m depth and increased to 1915 g at 8-9 m depth, which was considerable more than found at Læsø Trindel in 2012 even on the samples taken on top of the new boulders. We therefore expect that the process of colonisation of the new boulders is still in process towards a climax community.

Restoration of the reef has so far resulted in an overall increase in biomasses of almost 6-8 folds per m^2 seabed at the two depth intervals of 5-6 m and 9-10 m. The abundance of solitary species also increased considerably from 2007 to 2012 with a factor near 4 and 6, respectively, at the two depth intervals. Behind those estimates a couple of assumptions were used to calculate the new enlarged surface of hard substrate on the new larger boulders. The assumptions were that fauna and flora are only found on the top layer of the new boulders and that the new boulders did not pack in between each other. Both assumptions will give a conservative estimate of biomasses.

Brown and red algal species made up the majority of the biomasses in 2007. The two algal groups were still dominant in 2012 but the sea anemone, *Metridium senile*, was found with very high biomasses as well. *M. senile* was not recorded at all on the reef before the restoration project was initiated. In general, there was a shift towards a higher proportion of perennial algal species with higher biomasses, but some of the increment is definitely caused by a larger surface area created by the large boulders compared to the former seabed.

Bivalves were relatively more dominant in abundance in the investigation in 2007 whereas crustaceans and to some extent gastropods and anthozoans had taken over in the 2012 investigation.

Changes in the fish community structure were evident as a result of the reef restoration. The increase of the gadoids cod and saithe with a factor of 3-6 of primarily larger juvenile fish around 20-30 cm (which corresponds to age 1- and 2-year old fish) was not seen in the bottom trawl surveys for the Kattegat cod stock component (ICES 2012; Vinther & Eero 2013). Here estimates on age 1 cod in 2012 was somewhat higher compared to 2011 but still at a low level compared to historical levels and the spawning stock biomass still remains at a very low level (ICES 2012). This suggests that the restored area at Læsø Trindel functions as a nursery area for gadoids attracting fish from neighbouring areas as the restored area provides an increased foraging potential including both benthic prey species and smaller fish prey species as demonstrated from the stomach analyses (see below).

A highly notable finding in this study was the higher abundance of cod observed in the shallow part where cavernous reef structure had been re-established, indicating the importance of these shallow, high-profile, hard bottom habitats as nursery areas for a commercially important species. A similar higher concentration of cod in shallow, rocky habitat was observed by Stål et al. (2007). The results in this study highlight the need to establish the magnitude and depth strata of the loss of this type of habitat due to boulder extraction, which has taken place for more than a century in the shallow Danish waters.

The highest increase in number of brown crabs was outside the restoration area and suggests that there has been an overall population growth in the area and the overall trend probably cannot be attributed to the restoration of the reef. The lack of any response for lobster, which remained at very low levels also after the restoration, could be explained by the fact that lobster is a slow growing species that matures around age 5 to 6 years in Scandinavian waters (Agnalt 1999). An increase in the lobster population due to local recruitment therefore cannot be expected within the 4-year period investigated and could only originate from a migration of adult lobster from adjacent areas which apparently has not taken place.

The presence of fish in the stomachs of cod and saithe after the restoration implies a higher availability of prey fish for both fish species. This is further supported by the increased presence of cod and the introduction of saithe in the vicinity of the reef area after the restoration. Cod prefer rocky substrate (Gregory & Anderson 1997) probably because complex substrates provide both shelter and food and the species is able to optimize its foraging and minimize predation mortality. Cod is a highly cannibalistic species and may rely heavily on available refuge to prevent predation mortality from larger cod. Saithe is also a predatory species and may be attracted to the restored reef by the increased foraging potential.

The increased presence of crustaceans, in particular gammarids, and crabs (Caridea) observed in the benthic fauna study was utilized by the cod, where higher biomasses could be observed in the stomach contents as compared to before the restoration. This shows a direct coupling of the fish biomass to the development of benthic fauna and demonstrates the restored function of the reef for local trophic dynamics. The notable difference in fish species found in cod and saithe stomachs suggests that cod found most of their prey among the typical fish observed on the reef while saithe preferred pelagic fish species that were not necessarily caught on the reef (sandeel and horse mackerel).

Although there were small changes in the community structure of the typical reef fishes, the wrasses, there seemed to be no changes in the feeding of these species on the bottom fauna that developed on the restored reef. This may be due to their fidelity to rocky substrates and the continued presence of their preferred prey items.

The ecological benefit of the restoration project is an estimate of an extra gain in macroalgal vegetation and bottom fauna of approximately 6 and 3 ton ash free biomass, respectively. The project also resulted in an estimated surplus of nearly 700 million fauna individuals.

Mainly gadoids and reef fish benefitted from the restoration of the reef. Cod increased on average three- to six-fold in the reef area, especially in the shallow part where the cavernous reef structure was restored. The larger juvenile individuals of cod were attracted to the restored high-profile, shallow part of the reef and they profited from the increased food availability, mostly gammarids, which was the dominant prey item in the cod stomachs both before and after the restoration. The results of the stomach analyses demonstrated a benthic-pelagic coupling in the reef area, strengthened by the restoration of the reef. The increase in wrasses was less dramatic and was observed in the peripheral, deeper area of the reef.

A parallel study at Læsø Trindel conducted by Aarhus University (Mikkelsen et al. 2013) documented that the small cetacean, harbour porpoise, used the reef more frequently and for longer periods after the restoration project was conducted. This strongly indicates that the ecological quality of the reef as feeding ground had improved.

Lack of stable substrate caused by boulder extraction in former times, was one reason for the evaluation of an unfavourable reef condition for the habitat area Læsø Trindel and Tønneberg Banke. The restoration project with establishment of new stable boulders has clearly remedied this problem. Ongoing efforts to reduce nutrient loading to Kattegat and other management initiatives will likely change the conservation status to favourable in the future. From our observations of species composition and overall development of the algal vegetation at other boulder reefs in Kattegat, it is argued that the biological development in 2012 is far from a climax community. More species and first of all higher biomasses are expected in the years to come.

The overall aim of this project was to create a reef where a large part had crevices and steep slopes even to very shallow depths and with a harsh physical environment. The reason for this strategy was to benefit the presence of lobsters, edible crab and fish species. The benefits observed for cod in the shallow part of the restored reef demonstrate the importance of very shallow high-relief reefs.

An alternative strategy could have been to deploy the boulders over a larger area in a single layer avoiding the most exposed shallow part of the reef. In such a case, smaller and cheaper boulders could have been used and reduced the expensive handling time. Such a strategy would have resulted in a reef covering a much larger area and larger biomasses of benthic fauna and algal vegetation would be expected. Fish would benefit from the larger area due to the higher prey availability but the single layer boulders would result in fewer crevices and steep slopes. The less complex structure would provide fewer refuges for fish and thus overall may not result in a more favourable habitat for fish.

5 Perspectives for the future

Boulders from reef areas have been exploited as a resource for construction of harbours and other marine construction for centuries (Bock et al. 2003). This is in particular the case in the south western part of the Baltic Sea, where the marine seabed is shaped by glacial deposits and later erosion processes leaving boulders exposed on the seabed.

The marine ecosystem can benefit from boulder reef restoration projects by enhancing these highly productive and species rich habitats. Locally, leisure fishery will have better conditions for their activity and a positive effect is expected for the local tourist industry based on sightseeing boat trips and divers. Although the restored reef showed improved nursery habitat for a commercially important species, the scale may be insufficient to provide positive effects at the level of the fish population, from which the commercial fishery may benefit. The restoration scale required to provide benefits at the population level for commercial species is not known.

Restoring boulder reefs will also help improve the resilience of reef habitats as well as provide refuge for commercial fish populations with high affinity to high profile hard bottom habitats. Restored reefs with macrophyte forests in areas affected by low oxygen conditions, may also contribute towards improved water quality through the added production of oxygen in the sensitive later summer period and in preventing the recycling of nutrients that takes place during anoxic events (Møhlenberg et al. 2008).

Reef restorations will also help to minimize the effect of expected future loss in seaweed production caused by increasing water levels due to climate change. This reduced production, caused by reduced light penetrating through the water column down to the seabed, is expected to be especially crucial in coastal areas with low visibility (Dahl et al. 2012).

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Appendix 1

Sampling locations, anchor positions and sampling depths at Læsø Trindel in 2007.

Location	Anchor place	Position WGS-84		Station	Depth (m)
		Longitude	Latitude		
West	V1	5725.6638	1114.119	V1-1	9.9
				V1-2	9.9
	V2	5725.663	1114.1022	V2-1	9.8
				V2-2	9.8
				V2-3	9.8
	V3	5725.6819	1114.1648	V3-1	9.6
				V3-2	9.6
				V3-3	9.6
Middle	M1	5725.723	1114.53	M1-1	9.6
				M1-2	9.6
	M3	5725.6823	1114.443	M3-1	9.4
				M3-2	9.4
				M3-3	9.4
				M3-4	9.4
East	B1	5725.7245	1114.7425	B1-1	5.5
				B1-2	5.5
				B1-3	5.5
	B2	5725.679	1114.759	B2-1	5.9
				B2-2	5.4
				B2-3	5.5
				B2-4	5.2
	B3	5725.61	1114.761	B3-1	5
				B3-2	5
				B3-3	5.3
				B3-4	5.4
	B4	5725.7474	1114.7356	B4-1	6
				B4-2	6
				B4-3	6.2

Appendix 2

Sampling locations, anchor positions, stations, sampling positions on boulders and water depths at Læsø Trindel in 2012.

Sampling location	Anchor place	Position WGS-84		Station	Sample media	Depth (m)
		Longitude	Latitude			
Boulders						
West	V2	5705,66	1114,087	V2A-1-Sten	Boulder-top	8,8
				V2A-2-Sten	Boulder-top	8,9
				V2A-3-Sten	Boulder-top	9,1
				V2A-4-Side	Boulder side	9,4
				V2A-5-Side	Boulder side	9
				V2A-6-Side	Boulder side	8,9
	V3	5725,676	1114,148	V3-1-Sten	Boulder-top	8,7
				V3-2-Sten	Boulder-top	8
				V3-3-Sten	Boulder-top	8
				V3-4-Side	Boulder side	8,5
				V3-5-Side	Boulder side	8,5
				V3-6-Side	Boulder side	8,8
Middle	M1A	5725,719	1114,547	M1A-1-Sten	Boulder-top	8,9
				M1A-2-Sten	Boulder-top	8,8
				M1A-3-Sten	Boulder-top	9,1
				M1A-4-Side	Boulder side	9,4
				M1A-5-Side	Boulder side	9,5
				M1A-6-Side	Boulder side	9,9
	MT	5725,718	1114,535	MT-1-Sten	Boulder-top	8,1
				MT-2-Sten	Boulder-top	8,2
				MT-3,Sten	Boulder-top	8,3
				MT-4-Side	Boulder side	8,7
				MT-5-Side	Boulder side	8,8
				MT-6-Side	Boulder side	8,9
EAST	B2	5725,719	1114,764	B2-1-Sten	Boulder-top	4,8
				B2-2-Sten	Boulder-top	4,8
				B2-3-Sten	Boulder-top	4,8
				B2-4-Side	Boulder side	5
				B2-5-Side	Boulder side	5
				B2-6-Side	Boulder side	5
	B10	5725,771	1114,772	B10-1-Sten	Boulder-top	5,6
				B10-2-Sten	Boulder-top	5,6
				B10-3-Sten	Boulder-top	5,6
				B10-4-Side	Boulder side	5,6
				B10-5-Side	Boulder side	5,6
				B10-6-Side	Boulder side	5,6
	BS	5725,675	1114,692	BS-1-Sten	Boulder-top	5
				BS-2-Sten	Boulder-top	4,8
				BS-3-Sten	Boulder-top	5
				BS-4-Side	Boulder side	5,4
				BS-5-Side	Boulder side	5,5
				BS-6-Side	Boulder side	5,2
	B11	5725,79	1114,811	B11-1-Sten	Boulder-top	4,8
				B11-2-Sten	Boulder-top	4,7
				B11-3-Sten	Boulder-top	4,8

				B11-4-Side	Boulder side	5,5
				B11-5-Side	Boulder side	5,4
				B11-6-Side	Boulder side	5,1
	B12	5725,812	1114,799	B12-1-Sten	Boulder-top	6
				B12-2-Sten	Boulder-top	6,2
				B12-3-Sten	Boulder-top	5,8
				B12-4-Side	Boulder side	6,4
				B12-5-side	Boulder side	6,4
				B12-6-side	Boulder side	6,1
	BT	5725,683	1114,749	BT-1-sten	Boulder-top	3-3,5
				BT-2-sten	Boulder-top	3-3,5
				BT-3-sten	Boulder-top	3-3,5
				BT-4-sten	Boulder-top	3-3,5
				BT-5-Side	Boulder side	3-3,5
				BT-6-Side	Boulder side	3-3,5
				BT-7-Side	Boulder side	3-3,5
				BT-8-Side	Boulder side	3-3,5
Sandy/gravely seabed samples						
West	V2	5705,661	1114,088	V2-1-	Gravel/sand	9,2
				V2-2	Gravel/sand	9,2
				V2-3	Gravel/sand	9,2
Mid	M1B	5725,762	1114,54	M1B-1	Gravel/sand	10,2
				M1B-2	Gravel/sand	10,2
East	BN	5725,777	1114,768	BN-1-Ral	Gravel/sand	6,2
				BN-2-Ral	Gravel/sand	6,2

Ecological benefits from restoring a marine cavernous boulder reef in Kattegat, Denmark

By Claus Stenberg, Josianne Støttrup, Karsten Dahl, Steffen Lundsteen, Cordula Göke and Ole Norden Andersen

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